5-1-1977

Correlation Study Between Subjective and Objective Scene Classifications

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's Thesis of

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with a major in Printing Technology
has been approved by the Thesis Committee as
satisfactory for the thesis requirement for the
Master of Science degree at the convocation of

May, 1977

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CORRELATION STUDY BETWEEN SUBJECTIVE AND OBJECTIVE SCENE CLASSIFICATIONS

by

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An Abstract

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Printing in the College of Graphic Arts and Photography of the Rochester Institute of Technology

May, 1977

Thesis advisor: Milton Pearson

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ABSTRACT

In addition to the quality of an original (transparency or reflection) preferred halftone reproduction is also dependent on scene classification. That is, how the tones of the original are rendered. If the majority of the picture area contains light tones, it is referred to as a high key image. Should the majority of picture area be confined to dark tones, it is referred to as a low key image. When the picture area is composed of the entire tone scale (white, grays, and black), it is referred to as a normal key image.

The problem of how to objectively classify images into high, normal, and low key scene classification still continues in the graphic arts. The intent of this thesis was to determine if a scanning device could be attached to a HCM 286 Color Scanner and applied to a correlation study between the classification and ranking of images by observers and that of an objective measure of the images.

One experiment was devoted to psycho-physical testing in which several black and white photographs were subjectively classified and ranked into high, normal, and low key image types. Installation of the scanning device revealed complications that made it necessary to go ahead and obtain the objective data by using manual density measurements and a computer to derive the images' tone distribution curves (TDCs). The TDC is a statistical representation of the images' tone information; not a test object.

Because of the tediousness of manual density measurement brought about by the inavailability of the scanning device, only eight images were measured objectively. Based on the complexity of their TDC shapes, the existence of a real relationship between subjective and objective scene classification cannot be inferred presently. It is believed that this relationship can be found when a larger sample size of objective data is available. However, it is only reasonable to consider a larger sample size when a less tedious method becomes available, such as the scanning device. Discussions and recommendations are also given for further investigation between sequential viewing (one image at a time) and simultaneous viewing (all images at one time).

Abstract approved: Milton Pearson Thesis Advisor

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ACKNOWLEDGEMENTS

Completion of a task such as this would not be whole without the recognition of those who contributed valuable time and ideas. Sincere thanks to Milt Pearson for his suggestions and advice. My appreciation is also extended to Dr. Julius Silver and Dr. Mark Guldin for serving on my thesis committee. A very special thanks to Mary, Dave, Randy, JTF, TC, and Harvey for all their encouragement.

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I. INTRODUCTION

The fundamental objective of any tone reproduction study is to produce an identical rendition of an original scene. Albeit, it is virtually impossible to make an <u>exact</u> photographic facsimile of an original scene. One must realize that there are limitations in photographic materials and processing that restrict the photographic reproduction capabilities. These limitations dictate departures from the exact objective tone reproduction of an original scene. Fortunately, the human visual system does not require the photographic reproduction to have the exact luminances (measurable intensities of light stimuli) as those depicted in the original scene.[1]

In most practical instances, it is the photographer who must concern himself with the reproduction of an original scene. In doing so, he produces a photographic image of the original scene. Afterward, the printer is requested to reproduce that original image. But here again, like the photographer, the printer is restricted by his materials and processing. In the past it has been assumed one would like the density at every point of the reproduction equal to that of the original. However, the density range of the continuous tone original is usually longer than the maximum obtainable solid ink density range of the halftone reproduction. Thus, the tone scale of the original must be compressed within the tone limitations of the printing process.[2]

An objective tone reproduction study provides the printer with a means by which he can maximize his reproduction quality in spite of all the inherent limitations in materials and processing. Nonetheless, such a study is only relevant when the printing characteristics remain stable. Once these have been established, the reproduction quality can be controlled by standardization of each manufacturing phase for the entire printing process.

Tone reproduction study techniques have been available to the graphic arts for many years. Until recently, all halftone reproduction study techniques have been forced to include a tone reproduction test object, such as a gray scale, to be reproduced along with the original. Rather than trying to measure individual tone elements of the image itself, one measures the test object. Density measurements from the test object are used to derive the objective or preferred tone reproduction characteristics. These will become the halftone screening requirements needed to achieve the desired tone reproduction characteristics. The objective tone reproduction characteristics are expressed in terms of a curve whereby the density of the reproduction is plotted against the density of the original.[3]

One of the oldest and more popular graphical techniques for the systematic study of tone reproduction is the Jones type diagram.[4] When applied to a printing process, it displays several relationships involved in the reproduction of the original; the ink, plate, press, and paper combination. To derive the objective tone reproduction curve, the printing and halftone characteristics are graphically analyzed. Again, this information is generally obtained from some sort of test object. An example of the Jones diagram technique for black and white is explained in Appendix A.

General Problem

There has been a need for more precise optimum tone reproduction study techniques. The Jones diagram technique is rarely used for this evaluation. It seems that regular production takes precedence over time-consuming analyses. When it is used, the objective tone reproduction curve is derived for a specific type of original which is to be tested. More times than not, this one curve will be applied to all subsequent originals in the future, even though they may vary dramatically when compared to the tested original. While developing STORC, a simpler technique for optimizing tone reproduction, Archer and Elyjiw[5] found that preferred tone reproduction is tremendously influenced by the quality of the original. The majority of copy can be classified into four types of quality: contrasty, normal, low contrast, and very low contrast. In other words, the quality of an original is judged by its image contrast rendition and how it relates to the luminances of an original scene. The image contrast rendition is controlled by the sensitometric characteristics of the reproduction process.[6] Such factors as exposure and development will effect the subjective evaluation of an original. Graininess, sharpness, and resolution are other factors considered in quality evaluations.[7] Although STORC has eliminated time-consuming graphical analyses, it still requires the use of a test object.

In addition to the quality of an original, preferred halftone reproduction is also dependent on scene classification. That is, how the tones of the original are rendered. It is up to the discretion of the photographer and/or customer as to what part of the tone scale will contain the main interest area. The main interest area is that part of the image which is intended to attract the observer's attention. If the majority of the picture area contains light tones, it is referred to as a high key image. Should the majority of the picture area be confined to dark tones, it is referred to as a low key image. When the entire tone scale is used for the main interest area, it is referred to as a normal key image. This terminology implies the predominant tones of the main interest area. Even so, some parts of the main interest area could be on other portions of the tone scale.[8]

The Zone System

A somewhat more explicit definition of high, low and normal key can be deduced from what photographers refer to as the zone system. The zones are divided into nine categories related to tone gradation. The zone system analyzes the scene classification of tone reproduction by means of nine subjective descriptions and examples rather than density. It is interesting to note that a low key image must have a highlight in addition to its dark tones. On the otherhand, a high key image does not require a black; only light tones.[9] The zone system is described in more detail in Appendix B.

Statement of Problem Proper

Like Archer and Elyjiw,[5] others have found that preferred halftone reproduction is dependent on the contrast rendition of the original. Specifically, Jorgensen[8] has demonstrated the preferred tone reproduction curve of classified high key originals to be significantly different from that of images classified as normal and low key. In both studies, scene classification was purely subjective.

Consequently, a problem still persists in photomechanical reproduction. That problem is how to objectively classify originals. If the tone information of the originals could be expressed quantatively, it would provide an objective means of scene classification. Such a method may also alleviate the necessity of working with tone reproduction test objects since one would be dealing with measurements directly obtained from the image itself.

Past experience has shown that test objects are not truly representative of many original images.[10] Numerous discrepancies between test objects and originals are attributed to differences in their respective tone configurations. Processing variations resulting in adjacency effects, such as bromide drag and valing, may also lead to discrepancies.[11] Another possible cause, often ignored, is that of metamerism.[12]

Statistical Sampling

A new approach to the study of optimum tone reproduction has been developed by Ovchinnikov[13] and others of the USSR. They have introduced a system for programming the preferred tone reproduction curve of a wide variety of images which have different tone information. It is based on objective data that is obtained by optically scanning and statistically analyzing the informational part of the image. The informational part is considered to be the non uniform lightness areas which contain tone gradation. The non informational part is composed of the uniform lightness areas which have no tone gradation.

The instrument can measure the entire image or solely its informational part. Basically, it accomplishes this by simultaneously measuring two image points and comparing their differences to a pre-determined lightness value. Only those tones that exceed this threshold level are considered informational and are recorded and statistically sampled. The informational part of a high key image is presumed to be similar to that of a low key image since their respective light and dark tones have no tone gradation. Hence, these non informational parts are neither recorded nor sampled.[13] In effect, the informational part of an image is not contingent upon scene classification.

The Russians determined that a statistical lightness curve of the informational part of an image should resemble a Gaussian, bell-shaped curve. The tone reproduction curve is the transfer function necessary to transform the relative frequency histogram of lightness of the original image to the desired Gaussian curve. This concept makes it possible to produce optimum tone reproductions from poor tone quality originals. The optimum tone reproduction curve is derived by converting the lightness distribution from the informational part of the original through the tone reproduction curve to the Gaussian function. This process is said to yield a customized optimum tone reproduction curve for any type of original image.[13]

Tone Distribution Curve

A later, but similar approach to that of the USSR has been investigated by Chung.[12] It is similar in that the lightness information of the image was statistically analyzed.

However, his methodology and objectives differed in some respects. For example, he had no sophisticated scanner. His instrumentation consisted of a reflection densitometer interfaced with a computer. Due to this fact, the total image areas, both uniform and non uniform lightnesses, were included in the sampling.

The tone information of the original was also viewed differently. Statistical sampling of the tone information was expressed in terms of a tone distribution curve (TDC)[12] which is the relative accumulative frequency of the image lightnesses. The curve is derived by first obtaining a frequency histogram of image lightnesses with an in-line densitometer. The histogram gives the absolute frequency of densities appearing at various tone values in the image. A computer program then transforms the absolute frequency into its relative cumulative frequency. Also, the density values are converted into corresponding Munsell values. When the relative cumulative frequency of the sampled image lightnesses are plotted against their corresponding Munsell value, one has derived the tone distribution curve.

The TDC is a statistical representation of the image's tone information. It can be used to classify originals by scene type and contrast, in addition to determining their optimum tone reproduction curves. The ability to objectively classify images is significant in that it may permit a scanner to classify originals as well as reproduce them.

Once classified, the scanner could apply the preferred tone reproduction curve for that particular scene classification.[12]

Purpose

The purpose of this thesis is to determine if a scanning device can be attached to GARC's HCM 286 Color Scanner and applied to a correlation study expanding the work of Chung.[12] This study consists of five major experiments. One experiment is devoted to psycho-physical testing in which several black and white photographs are subjectively classified and ranked to be indicative of high, normal, and low key images. The next phase concerns the installation and debugging operations of the scanning device. One subsequent experiment involves manual density measurements from eight of the pre-tested images to obtain their objective TDC attributes. The last experiment entails a statistical comparison of the subjective classification of the images versus their objective characteristics as determined by their TDC.

Assumptions

A random sampling of the entire tonal content of the images was used. In this case, there is a single true tone distribution curve for any one given image. More importantly, it is assumed that this true curve is obtainable by scanning all the tone values and statistically analyzing them when they are independent from one another.[12]

Research Questions

The research questions concern two aspects. First of all, can a scanning device be attached to a modified color scanner so that it will read all the tone information contained in a given image?

The second and most important research question: is it possible to subjectively classify an image and then obtain an objective classification from a statistical analysis of the lightness of the image?

Hypothesis

The following is expressed as a null hypothesis: there is no significant correlation between the classification and ranking of images by observers and that of an objective measure of the images.

No association between the given conditions is to be initially presumed. One will be able to infer the existence of a real relationship if and when the null hypothesis should be accepted.

FOOTNOTES FOR CHAPTER ONE

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II. LITERATURE REVIEW

Lightness Values

In order to perform a systematic analysis of tone reproduction, one must have some means of obtaining information about the original and its reproduction. One such medium is that of density measurement. However, density measurement does not correspond with the manner in which the human visual system perceives lightness. A gray scale with equally spaced density increments tends to have less visual separation in the dark areas than in the grays.[1] Unlike the eye, density operates on logarithmic intervals.

Both Rhodes[1] and Yule[2] have recommended the conversion of density values into Munsell values because it more readily approximates the responses of the human visual system. A gray scale with equally spaced Munsell increments has a more equal visual separation between steps than that of density increments.

Bartleson and Brenneman[3] have also developed a lightness scale which corresponds more accurately to the human visual system. It is based on a power function. It was derived from the lightness-luminance relationship between reflection prints or transparencies and the original scene for a range of illumination levels.

The USSR has also derived a lightness scale.[4] Chung[5] found twenty equal increments of the USSR lightness values to be very similar to ten equal Munsell value increments. Figure 1 shows Chung's transformation curves of density to Munsell, density to Bartleson Brenneman's lightness scale, and density to the USSR lightness scale.

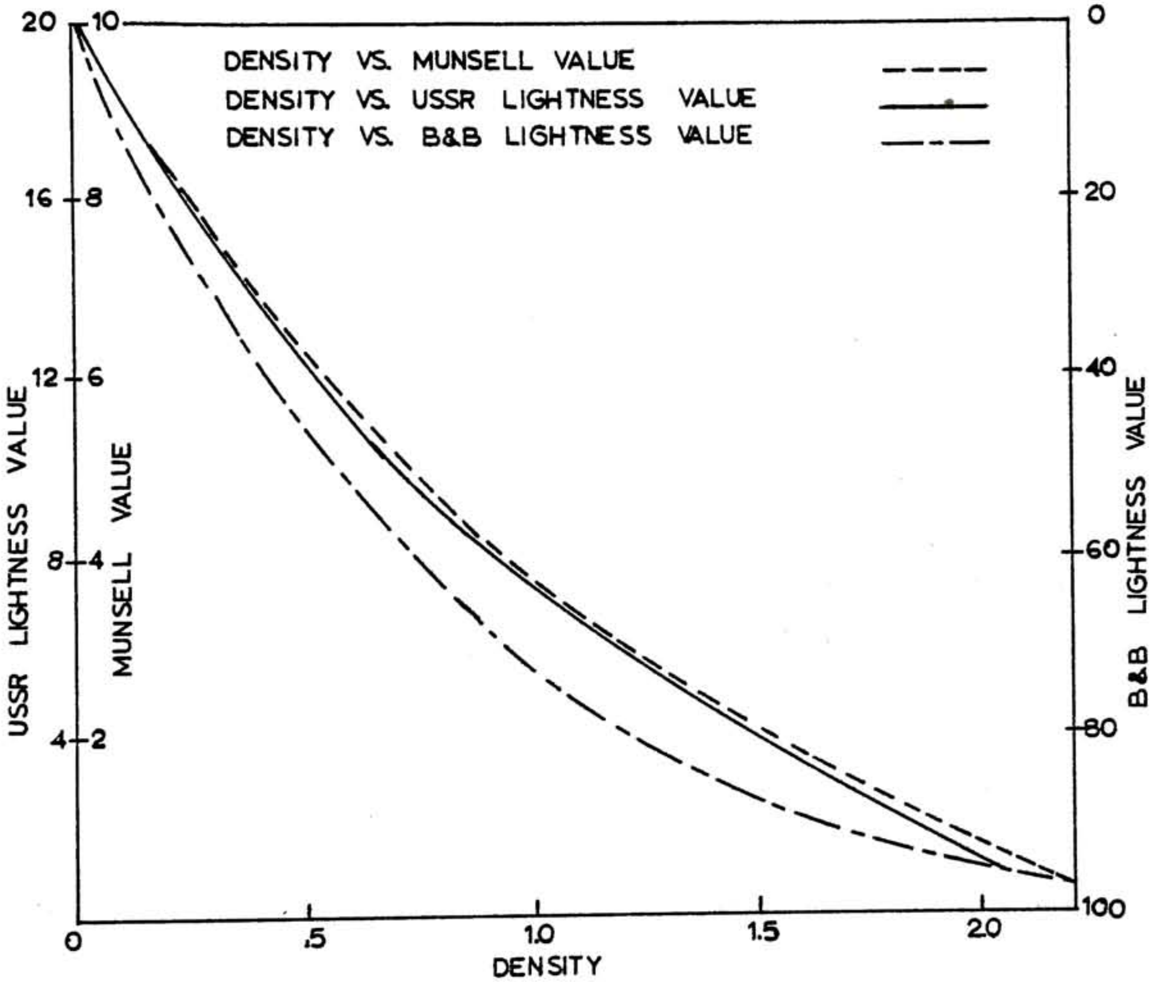

Figure 1.
Chung's transformation curves of Density to Munsell Value, Density to USSR lightness value, and Density to Bartleson and Brenneman's lightness value.[5]

Preferred Tone Reproduction

Preferred tone reproduction in continuous tone photography has been explored for many years. In spite of investigations by Bartleson and Brenneman,[3,6-7] Clark,[8] Jones and Nelson,[9-11] Simonds,[12-13] and others; the human visual system is still not fully understood.[14]

Yule[2,15-16] has applied various aspects from some of these previous studies to the problem of optimum tone reproduction in the halftone process. Again, the problem involves compressing the density range of the continuous tone original within the tone limitations of a particular printing process. One of his studies revealed that the print most often chosen for the most accurate reproduction exhibited more highlight contrast and appeared darker than the print most often chosen for the best picture quality.[2] The most accurate reproduction was selected to match the original: by comparing it to the original. Best picture quality was selected on the print's own merits: without comparison to the original. As a result, quality judgments are significantly affected by the presence or absence of the original during such evaluations. A graphical illustration of this finding is given in figure 2.

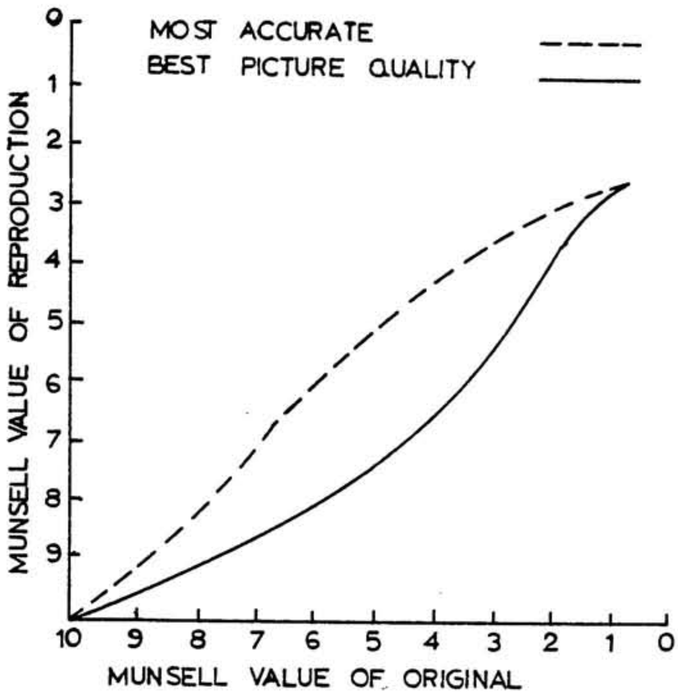

Figure 2.
The most accurate reproduction has a tone reproduction curve with a slope near 1 in the highlights. The tone reproduction curve for best picture quality has a slope near 1 in the midtones.[2]

Scene Classification

Although the literature of the past has compiled a respectable number of studies relevant to tone reproduction per se, [1-4,6-15] very little has been said for tone reproduction in specific regard to scene classification.[17-21]

Archer[17] was one of the first to recognize the implications of including non representative tone reproduction test objects during the reproduction of an original. The tone reproduction curve derived from such test objects will often fail to render the desired tone reproduction.

Twelve photographs were chosen to encompass the spectrum of scene classification. All twelve images were ganged in a copy board along with a regular ten step reflection gray scale. Ten negatives, one made to match each step of the gray scale, were then processed and contacted to minimize fringe. The integral densities of the positives were later measured densitometrically and expressed as a percentage area related to each of the ten steps.[17] The average density distribution curve for each of these images was found to be generally horizontal as shown in Figure 3.

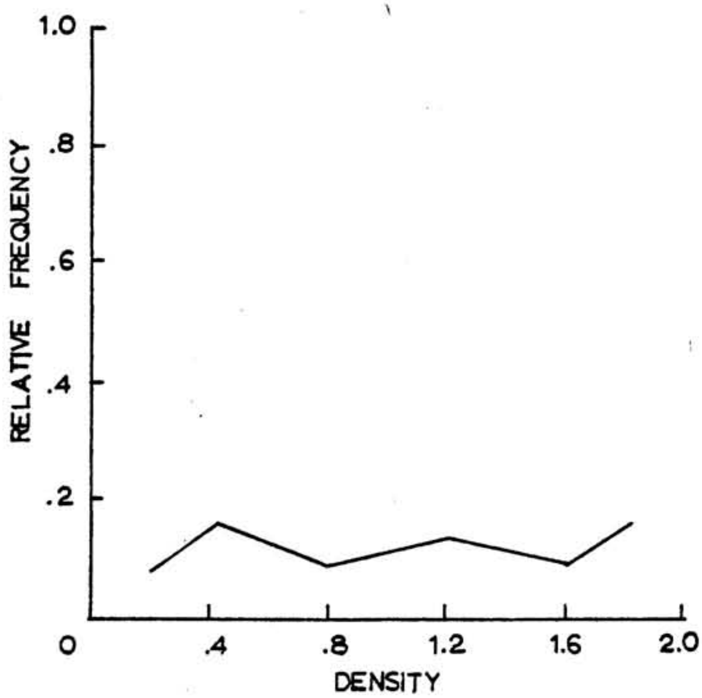

Figure 3.
The average density distribution curve of the twelve tested images is generally horizontal.[17]

A later study by Archer and Elyjiw[18] pointed out that the quality of an original is judged by its image contrast rendition. They developed a technique for optimizing black and white halftone reproduction that determines the effects of various screening conditions on four different test prints. It is based on the assumption that the majority of copy can be combined into four classifications of quality which visually appear to be contrasty, normal, flat, or very flat.

Jorgensen[19] also found preferred black and white halftone reproduction to be influenced by the image contrast rendition. He substantiated Yule's findings[2] by repeating, with one exception, the same basic subjective ranking procedures. But, due to the fact that a reproduction is ordinarily viewed without comparison to its original, he chose picture quality as the basis of his work. Although he did not actually test a low key image, he speculated it to have the same basic preferred tone reproduction curve as a normal key image. He determined the preferred tone reproduction curve of a high key image to be significantly different from that of a normal and low key image. He proposed the use of more than one optimum tone reproduction curve because he considered the main interest area of an image to be dependent on its scene classification. Therefore, the main interest area should have the <u>least</u> amount of tone compression. Figure 4 summarizes the results of his investigations.

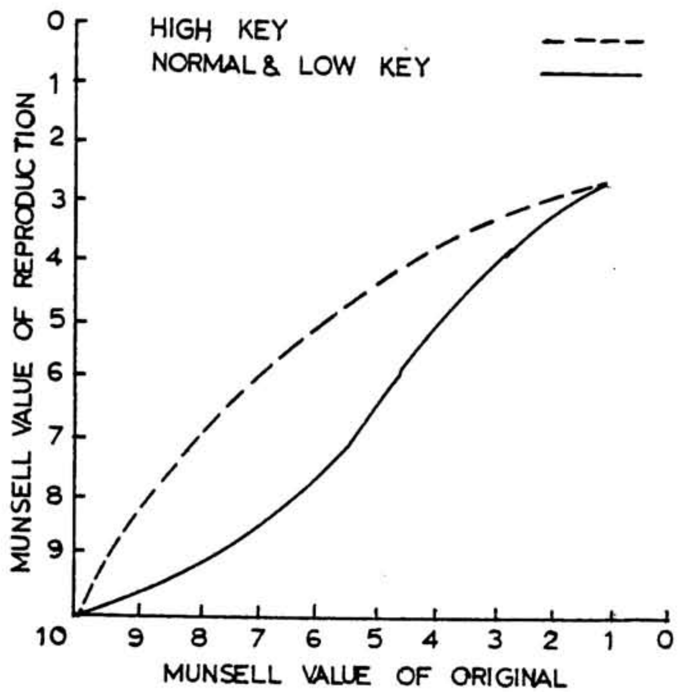

Figure 4.
The preferred tone reproduction curve of a high key image is shown to be quite different from that of a normal and low key image.[19]

Statistical Sampling Approach

Ovchinnikov[20] and others of the USSR have developed a new approach to the study of optimum tone reproduction. Their technique allows one to program the preferred tone reproduction curve of a wide variety of originals which have different tone information. It uses objective data that is obtained by optically scanning and statistically analyzing the informational part of the image.

Their scanning device can measure the entire image or solely its informational part. It accomplishes this by simultaneously measuring two image points and comparing their difference to a pre-determined lightness value. Only those tones that exceed a threshold level are considered informational and are recorded and statistically sampled. The informational part of a high key image is presumed to resemble that of a low key image because their respective light and dark tones have no tone gradation. These non informational parts are neither recorded nor sampled.[20] Consequently, the informational part of an image is not contingent upon its scene classification.

A very basic diagram of the scanning procedure is given in Figure 5. An original is placed on the rotating drum of an optical scanner. The device takes the light signals from the scanned areas of the image and converts them into electrical signals via the photoelectric detector. The electrical signals are then changed into signals that are proportional to optical density. The optical density signals are subsequently transformed into other proportional lightnesses. These conversions are performed by two nonlinear amplifiers. The scanner simultaneously measures an image point and determines whether or not there is a difference to a predetermined lightness value.[20]

Elimination of the non informational part of an image is determined by a computer interface which monitors the scanning procedure. The computer samples only those signals that have tone variation; the informational part of the image. The tone variations are compressed into twenty lightness levels corresponding to optical lightness values. This is achieved by a pulse amplitude analyzer. Next, register counters record the number of times a particular lightness level occurs. This information is put on perforated tape and fed into the computer. The computer translates the information into a relative frequency histogram of lightness which represents the tone gradation of a given image.[20]

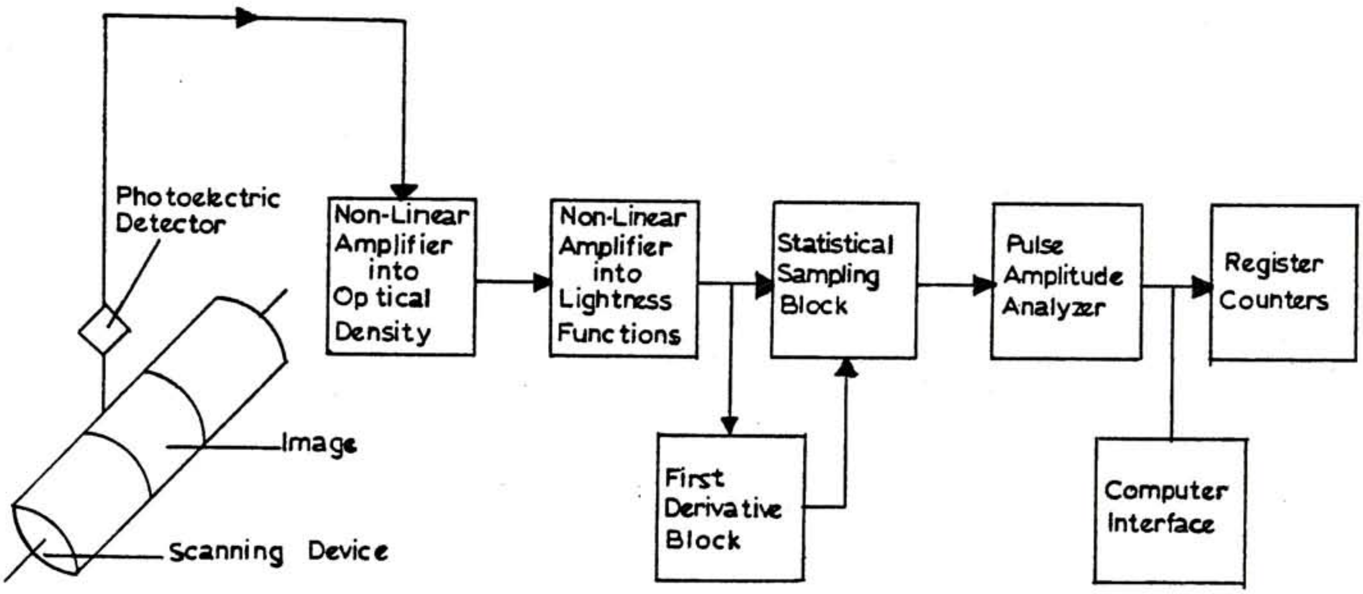

Figure 5.
Basic diagram of USSR Scanning Analyzer.[20]

The Russians determined that a statistical lightness distribution curve of the informational part of an image will resemble a Gaussian, bell-shaped curve. The tone reproduction curve is the transfer function necessary to transform the frequency histogram of lightness of the original image to this Gaussian distribution. The optimum tone reproduction curve is derived by the function necessary to change the informational part of the image to the Gaussian function as indicated in the graphical method shown in Figure 6.

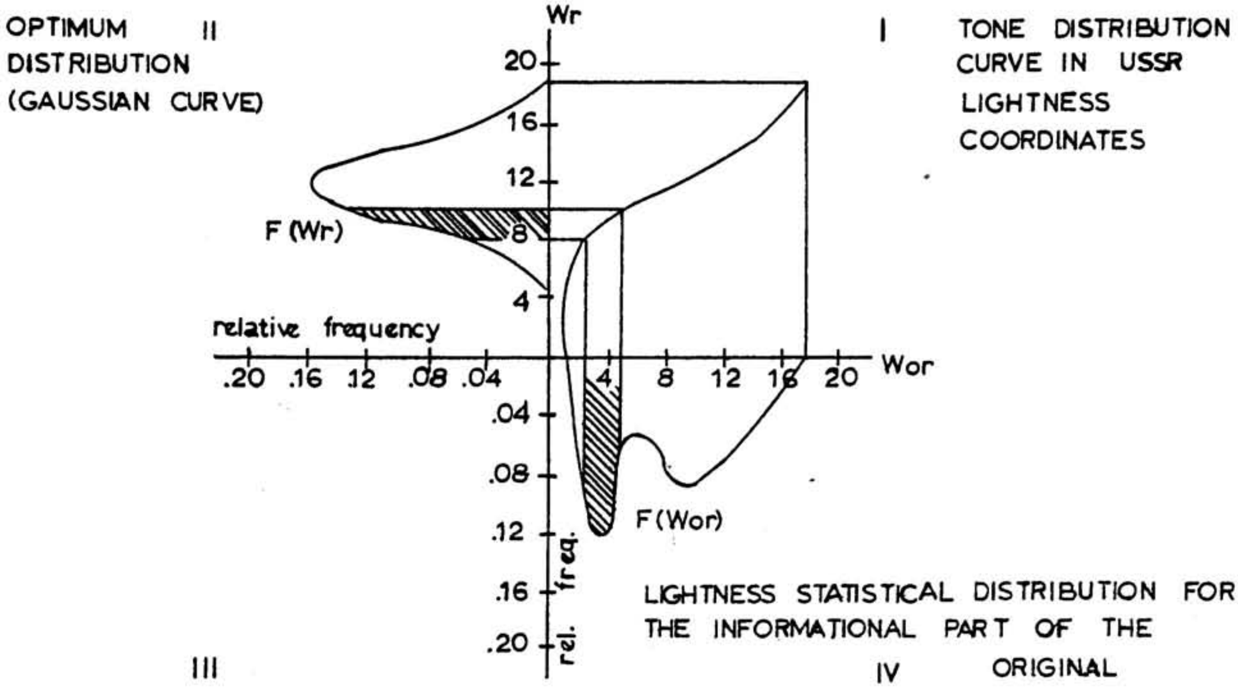

Figure 6.
USSR technique for graphically deriving the optimum tone reproduction curve.[20]

Quadrant IV of Figure 6 illustrates the lightness statistical distribution for the informational part of the original image F(Wor). It is obtained by plotting the frequency against the USSR lightness values of the original as designated by Wor in quadrant IV.

Quadrant II contains the Gaussian distribution that is used to transform the frequency histogram of lightness of the original (quadrant IV) to the desired tone reproduction in quadrant I.

Quadrant I contains the desired tone reproduction curve in USSR lightness values. It is derived by plotting the lightness of the reproduction (Wr) against the lightness of the original (Wor) via the intermediary Gaussian distribution. This method is said to yield a customized optimum tone reproduction curve for any type of original image.[20]

TDC Technique

A similar approach to that of the USSR has been recently explored by Chung.[21] It is similar in that the lightness information of the image itself was statistically analyzed. But, due to the lack of a sophisticated scanner, his methodology and objectives differed. His instrumentation consisted of a reflection densitometer interfaced with a computer. As a result, the total image areas, both uniform and non uniform lightnesses, were included in the sampling.

Chung also viewed the tone information of the original differently. He expressed the statistical sampling of the tone information in terms of a tone distribution curve.[21] The TDC is the relative accumulative frequency of the lightnesses of the image. Such a curve is derived by initially using an in-line densitometer to obtain a frequency histogram of the image lightnesses. The absolute frequency of densities occuring at various tone values in the original are accounted for in the frequency histogram. The absolute frequency was then transformed into its cumulative relative frequency by a computer program. The computer also converted the density values into Munsell values. One finally derives the tone distribution curve (TDC) by plotting the relative cumulative frequency against the Munsell values of the image.

The tone distribution curve is a statistical representation of the image's tone information. The intended use of the TDC approach is to objectively differentiate between high, normal, and low key image types. It can be used to classify, as well as determining their optimum tone reproduction curves.

Literature Review Summarization

The pertinent literature of the past has accumulated a vast amount of knowledge related to tone reproduction per se. The investigations encompass all sorts of approaches to the ensuing problems encountered in continuous tone photography and/or the halftone reproduction process. Albeit, very little has been published concerning tone reproduction with specific regard to scene classification.

As mentioned earlier, the intention of the TDC approach is to objectively distinguish between high, normal, and low key image types. The ability to classify images objectively is significant in that it may eventually permit a scanner to classify images as well as reproduce them. Once classified, the scanner could apply the tone reproduction curve for that particular scene classification. Further exploration of this objective technique may help solve the nebulous inconsistencies of subjective scene classification.

FOOTNOTES FOR CHAPTER TWO

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2. Yule, John A.C., "The Optimum Tone Rendering in Halftone Reproduction Processes," Halftone Printing, Vol. 3, Pergaman Press, New York, 1964, p. 17-42.

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20. Ovchinnikov, Yu. and others, "A New Approach to Programming in Photomechanical Reproduction," The 12th IARIGAI Conference Proceedings, Versailles, France, 1973, p. 160-163.

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III. SUBJECTIVE METHODOLOGY

Selection of Images

Thirty-one black and white photographs were selected from a series of prints. These images were selected to represent a sampling of the entire gamut of high, normal, and low key images. They were also chosen to approximate the range of quality that a printer might presumably encounter in a real world industrial situation. Some of the photographs depicted obvious scene classifications of high, normal, and low key. Classification of the remaining images was not so obvious. Dimensions of the images varied from 5 x 10 inches to 8 x 10 inches. They were printed on a variety of paper grades and surface textures.

Selection of Observers

Twenty-two people were asked to rank the photographs on a scale of one to nine according to low, normal, and high key. The population consisted of ten experienced and twelve naive observers. The experienced participants encompassed reproduction photography technicians from Graphic Arts Research Center, reproduction photography instructors, and senior students from the Schools of Photography and Printing. The naive observers were comprised of individuals outside the Schools of Photography and Printing. They had no working or formal association with tone reproduction.

Subjective Sealing System

The first experiment concerned the subjective scaling of images. Before the psycho-physical test, each print was identified by a number on the back. All thirty-one prints were presented to the observers in one random order that was shuffled just before each observer began. Each viewer sequentially classified and ranked the prints according to an arbitrary scale of nine values as given in Figure 7. Values one through three represent images thought to be low key. Images considered to be normal key were to be scored within scale values four through six. Values seven through nine represent high key images. The observers were shown an obvious example of low, normal, and high key images as an attempt to calibrate the scale and to minimize confusion. The obvious examples (Appendix D) were provided to correspond closely with the respective scale values of one, five, and nine.

Figure 7.
Arbitrary nine value scaling system for the subjective scene classification and ranking of images.

Viewing Conditions

The viewing conditions were measured with a foot-candle meter to assure a light intensity range of 30 to 100 foot candles as recommended in similar studies.[1] This phase of the psycho-physical testing was conducted in a modified Macbeth viewing booth under an average light intensity of 60 foot-candles; when measured on a 45° wooden viewing stand (Figure 8). Instructions for the psycho-physical testing are provided in Appendix C.

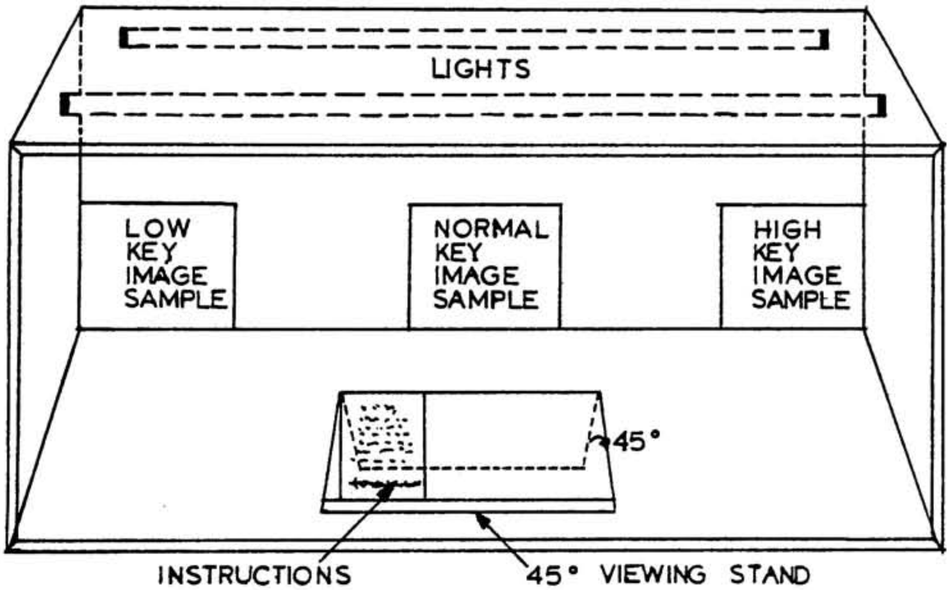

Figure 8.
Diagram of Macbeth viewing booth used for the subjective ranking of images.

Averaging of Subjective Scores

The responses to the subjective evaluations were based on the averaging of the subjective scores. After all observers had made their evaluations, the mean score at each scale value was determined for each print number. A computer listing of the subjective raw data and statistics can be found in Appendix E. Discussions concerning the results of the subjective raw data appear in Chapter V - Results.

FOOTNOTES FOR CHAPTER THREE

1. Mees, C.E.K. and James, T.H. (editors), The Theory of the Photographic Process, Macmillan, New York, 1966, p. 464.

IV. OBJECTIVE METHODOLOGY

Installation of Scanning Device

Electronics added to the optical scanning device were to derive the objective data for the calculation of the images' tone distribution curves. These electronics were installed on a HCM 286 Color Scanner for this purpose.

First testing of this electronic modification indicated that it was responding in the reflection mode rather than density as originally desired. In addition to this, the response was limited to an input signal range of only zero to 1.0 in density. A range of zero to at least 2.0 would be necessary to accommodate the density range of an average black and white photograph.

It was judged that the time factor necessary to correct these objections would be too great to be compatible with the time limits of this thesis. While these corrections are being made, it was judged necessary to go ahead and obtain the data by using much of the same methodology outlined by Chung.[1] However, because this was a manual and very time-consuming process, the objective measurements had to be limited to a sampling of only eight prints.

Acquisition of Data via Densitometer

"Generating a TDC from an image can be quite laborious in the absence of a specialized scanning and computing device because a fairly large number of measurements and a large amount of data manipulation are required."[2]

A Macbeth RD-514 densitometer was used to obtain the data for calculation of the images' TDCs. The densitometer was interfaced with a PDP-8 computer in the School of Printing. The computer was programmed to arrange the input density measurements into density cell intervals. The density cell sizes were adjusted to equal Munsell increments.[3] Munsell increments were chosen because they more readily approximate the perception of the human visual system.[4] The program for this is given in Appendix F.

Construction of Film Overlay

The next step was to devise an overlay to conveniently sample the images. It was constructed from an exposed sheet of 11 x 14 inch pan masking film with an average overall density of about 0.30. The film overlay had been punched with a row and column array of holes equal to the diameter of the hold-down aperture of the densitometer. These constituted a sampling of 285 data points.

In testing the densitometer with the overlay, it measured the same spot .01 to .02 higher through the overlay than without. The measurements remained consistent during a second testing when the overlay was used exclusively. As a result, the densitometer was calibrated using the overlay.

Calibration and Sampling

The densitometer was calibrated with the manufacturer's two-point calibration plaque through the same overlay used to sample the images. Calibration of the densitometer preceeded the sampling of each image. The film overlay was positioned over the image and marked in such a way that it could be shifted half the punch interval; horizontally and vertically.

This procedure permitted sampling of different size images whereby all data points were independent (no overlap of measurements). A total of 285 sampling areas were objectively measured for each image.

Selection of Images to be Measured Objectively

Due to the lack of time and tediousness of this technique, only eight images were measured objectively. They were selected on the basis of their subjective scaling averages and standard deviations. (Figure 9). The first three images to be sampled were those with the lowest standard deviations and averages approximately centered in each of the three categories of low, normal, and high key classification. Statistically, all observers generally agreed these were the most representative samples of low, normal, and high key images (Figure 11). Selection of the next three images was determined by the fact that they had the highest standard deviations for their respective scaling averages (Figure 9). These were the samples that seemed to present the greatest amount of variation among the observers (Figure 12). The last two images were chosen because their subjective mean scores were in between those of the most representative and the most questionable samples of low key and high key (Figures 9 and 14).

Calculation of TDCs

The tone distribution curve is a statistical representation of the images' tonal information. It results in a curve expressing the relative accumulative frequency of the lightnesses of the image.[1] Eight such TDCs were derived through the following procedure.

Sampled input density measurements were initially sorted into equal Munsell value intervals by the PDP-8 computer in the School of Printing. All of this data was subsequently punched onto paper tapes. The tapes were then fed into a teletype interfaced with the Xerox Sigma IX computer at Rochester Institute of Technology. The Sigma IX was programmed in APL language. APL is a high level programming language especially well suited to the calculations on arrays of data.[5]

All Munsell data on tape was sorted into twenty equal Munsell intervals by the APL functions listed in Appendix G. These same functions also computed the relative cumulative frequency of tones occuring at each Munsell interval.

$$\text{rcf} = \frac{\sum_{i=1}^{i} f_i}{n}$$

f_i = absolute frequency; number of measurements for each Munsell interval.

$\sum_{i=1}^{i} f_i$ = cumulative frequency; number of measurements for <u>all</u> Munsell intervals (20).

n = sample size; total number of sampling measurements.

i = number of Munsell interval.

The absolute frequency was used to calculate the cumulative frequency. Dividing the cumulative frequency by the sample size produced the relative cumulative frequency of the sampled lightnesses. The relative cumulative frequency was chosen as the response parameter because it yielded a curve similar to a regular tone reproduction curve when it was plotted against corresponding Munsell intervals. It also has a statistical advantage. Once a tone is selected, the percentage of tones for any value is automatically known by its relative cumulative frequency. Appendix H contains the APL computed data analysis used to plot the TDCs sampled by the densitometer. The plotted TDCs can be found in Figures 11, 12, and 13.

FOOTNOTES FOR CHAPTER FOUR

1. Chung, Robert Y., "A Statistical Method for Image Classification and Tone Reproduction Determination," Journal of Applied Photographic Engineering, Vol. 3, No. 2, Spring 1977, p. 74-81.

2. Ibid., p. 75

3. Yule, John A.C., Principles of Color Reproduction, John Wiley and Sons, New York, 1967, p. 354.

4. Yule, John A.C., Plot Tone Reproduction Curves, Graphic Arts Research Center, Rochester Institute of Technology, Rochester, New York, Report No. 127, 1968, p. 1-11.

5. Katzan, Harry Jr., APL Programming and Computer Techniques, Van Nostrand Reinhold Company, New York, p. 1-329.

V. RESULTS

Subjective Scene Classification

The subjective classification and rank order of prints are illustrated in Figure 9. The print numbers are arranged according to their mean subjective scaling score (Appendix E). The scores were plotted and the corresponding standard deviation was indicated for each data point by the magnitude of the vertical line passing through each data point. Subjective classification of the prints in their ranked order did show a fairly smooth progression from low to high key.

Correlation Between Experienced and Naive Judges

In order to determine the relationship between experienced and naive observers, a scatter diagram (Figure 10) was plotted. It shows the degree of relationship between the sample mean scores of the experienced judges plotted against those of the naive. Since most of the data points nearly form a 45^{o} line; one can assume there is a good relationship between naive and experienced observers. A linear regression computed by Sigma IX (Appendix I) derived the correlation coefficient r to be 0.98. The r value[1] is a measure of the degree to which scores of the experienced observers are associated with scores of the naive.

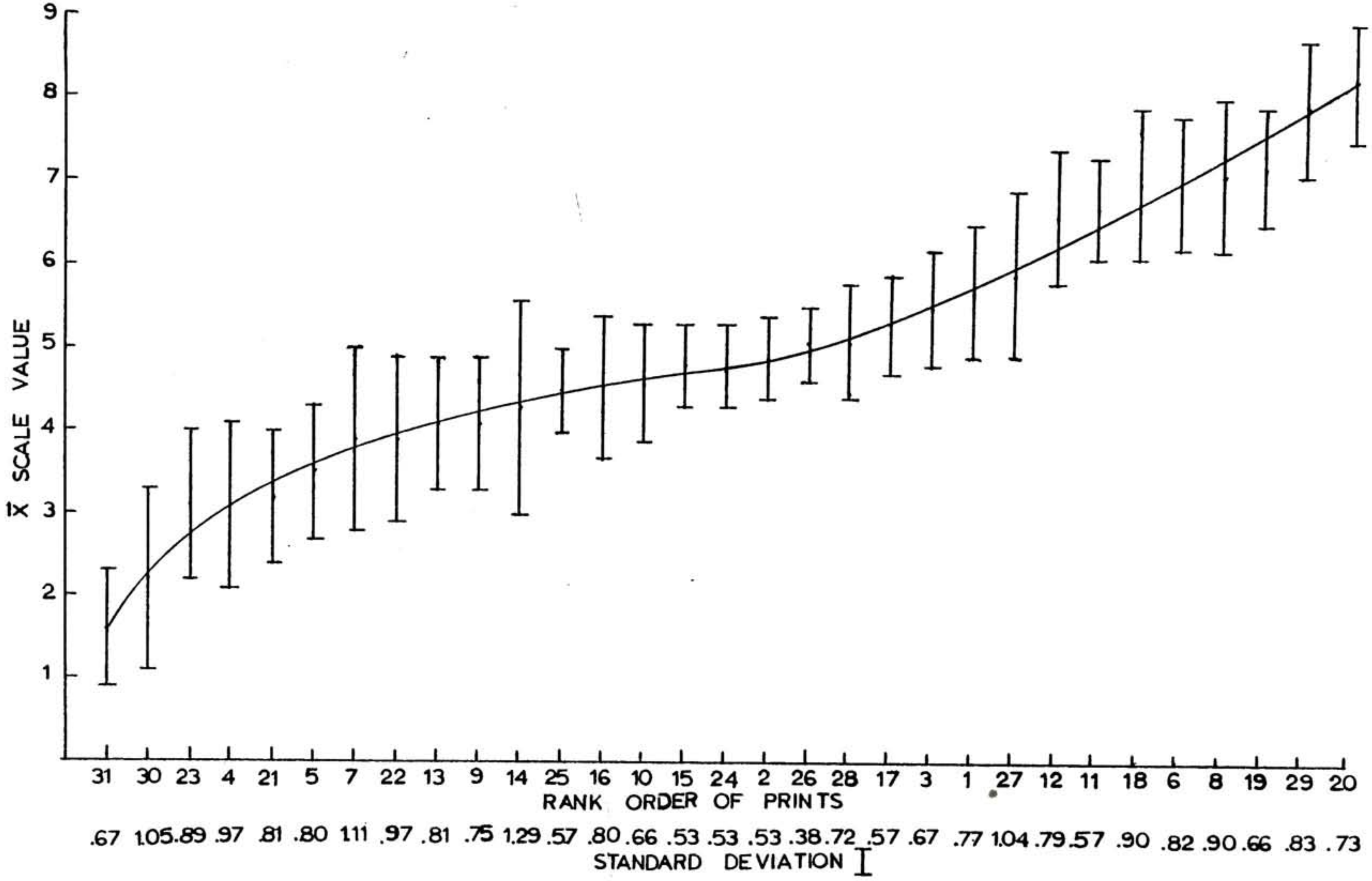

Figure 9.
Graphical illustration of subjective classification and rank order of prints.

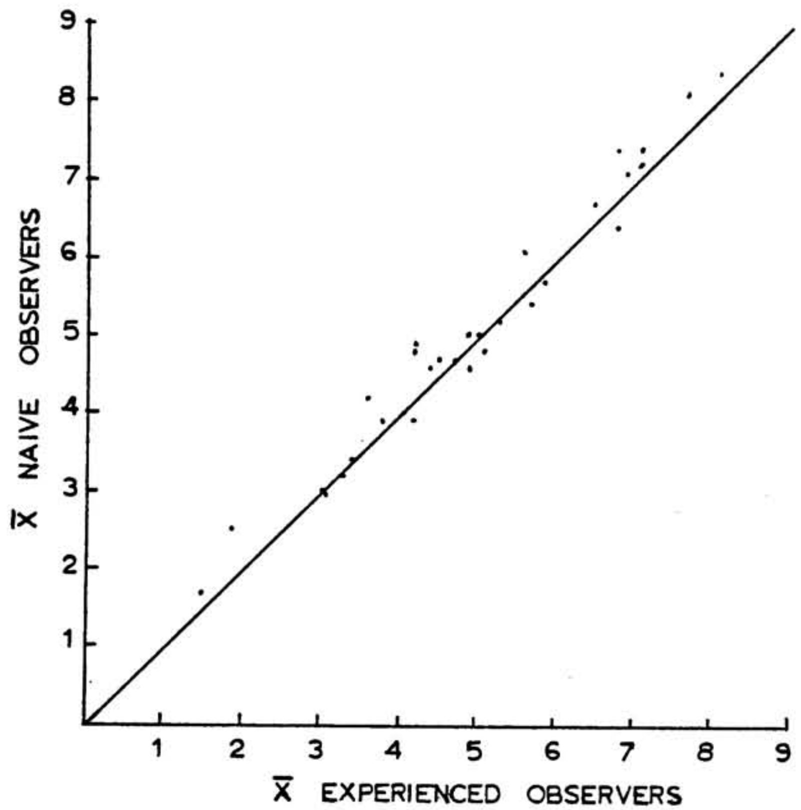

Figure 10.
Scatter diagram showing the degree of relationship between experienced and naive observers.

Graphical Presentation of TDCs from Eight Images Sampled by the Densitometer

The first three images to be examined were those with the lowest standard deviation in each of the three categories of low, normal, and high key. Their tone distribution curves, Figure 11, conform very closely with Chung's[2] suggested curve shapes for low, normal, and high key.

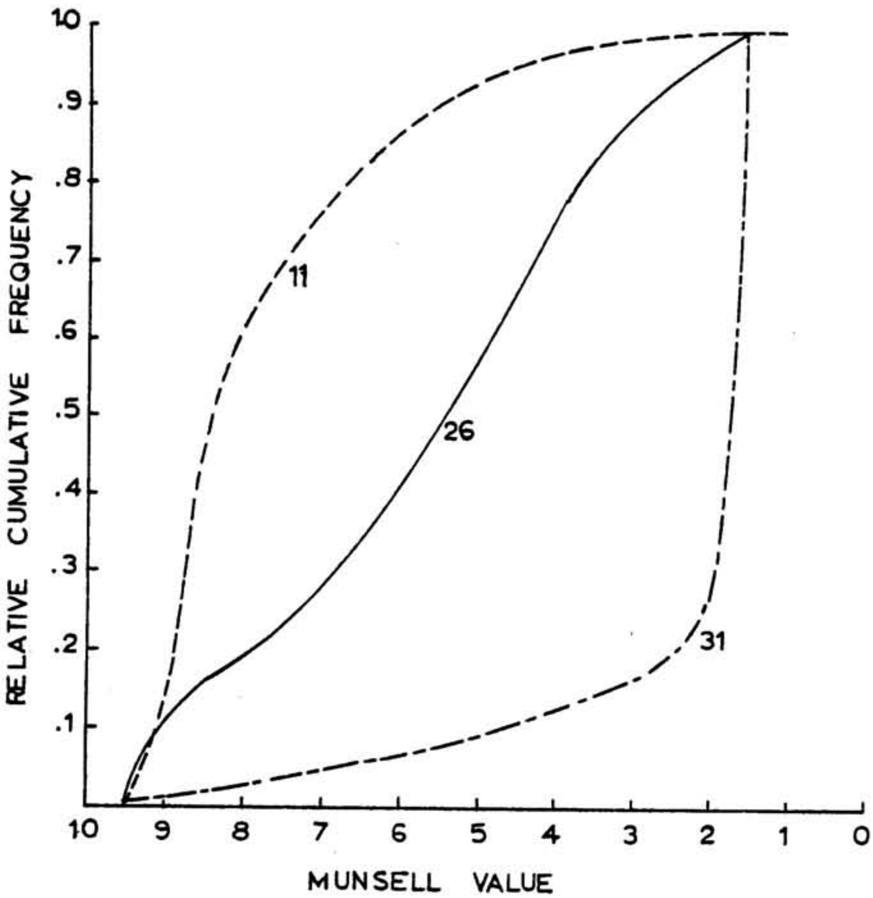

Figure 11.
Tone Distribution Curves of prints with lowest standard deviations for high key (print 11), normal key (print 26), and low key (print 31).

The tone distribution curves of the next three images were plotted because they had the highest standard deviation in each of the three categories. Figure 12 shows their TDC shapes were quite different from those with the lowest standard deviation.

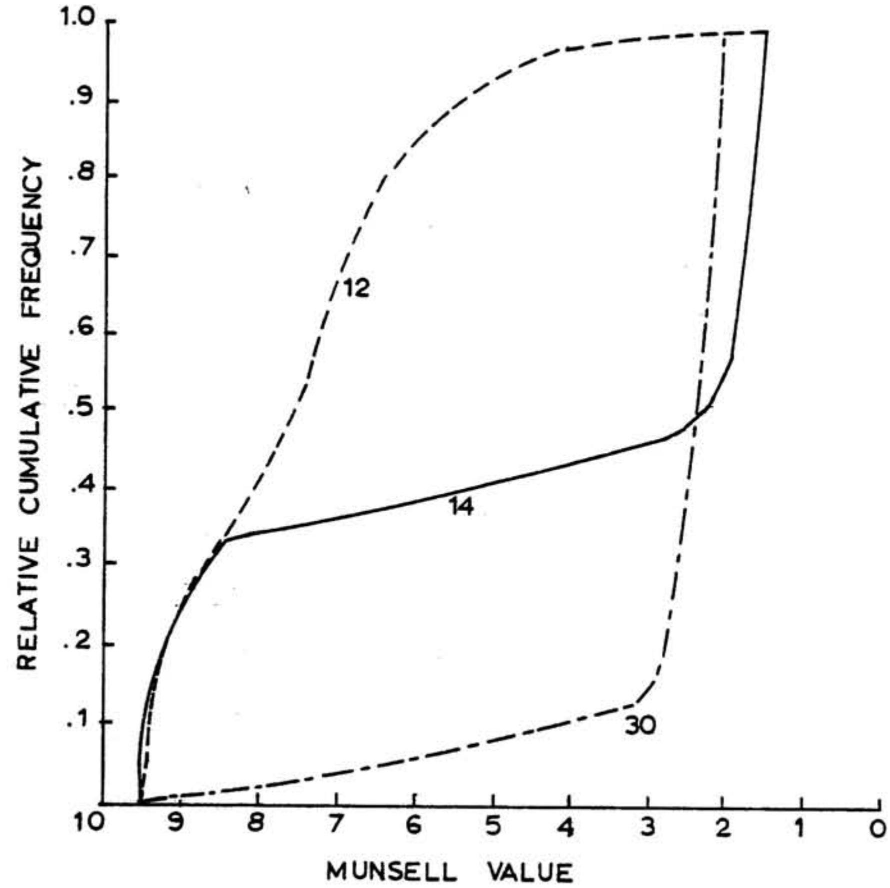

Figure 12.
Tone Distribution Curves of prints with highest standard deviation for high key (print 12), normal key (print 14), and low key (print 30).

The last two TDCs were plotted from prints ranked intermediately between high and normal and normal and low key. From the illustration in Figure 13, one can see these tone distribution curves present even more variation of TDC shapes.

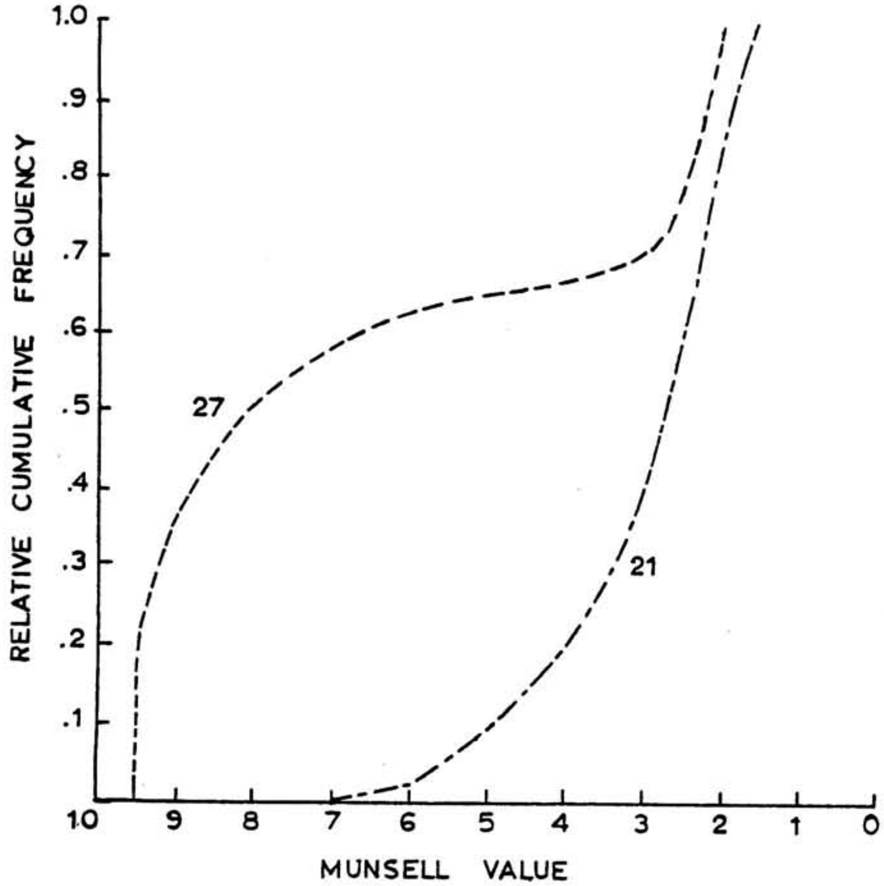

Figure 13.
Tone Distribution Curves of prints ranked between high and normal key (print 27) and normal and low key (print 21).

Correlation Between Subjective Sealing and Objective Measurements

From the complexity of the eight curve shapes, it was judged that not enough information was available to draw a conclusion to the proposed hypothesis in Chapter I. It is postulated that it would be necessary to calculate the tone distribution curves of all (31) prints before making any real correlation. The reason this was not done was: lack of time due to the tediousness of manual measurement brought about by the inavailability of the scanning instrument. On the basis of the information gathered thus far, the null hypothesis cannot be accepted. Although the existence of a real relationship between subjective and objective scene classification cannot be inferred presently; it is believed that a real relationship does exist and that this relationship can be found when a larger sample size of objective data is available.

FOOTNOTES FOR CHAPTER FIVE

1. Rickmers, Albert D., and Todd, Hollis N., Statistics, An Introduction, McGraw-Hill Book Company, New York, 1967, p. 254.

2. Chung, Robert Y., "A Statistical Method for Image Classification and Tone Reproduction Determination," Journal of Applied Photographic Engineering, Vol. 3, No. 2, Spring 1977, p. 74-81.

VI. DISCUSSION

Observations During Subjective Testing

In regard to time involved in making subjective judgements, naive observers were generally able to complete their evaluations earlier than experienced observers. It is assumed the experienced people tend to criticize; an expected influence from their professional or educational experience. It is also assumed the naive observers look at an image for what it is; not for technical expertise. Upon completion of their evaluations, each person was asked what it was they were looking at when they determined their judgements for low, normal and high key images. Many of them mentioned they viewed the images in terms of a balance of tones and/or a predominance of tones (white vs. gray vs. black)

Biased Distribution of Prints

During a surface investigation of the subjective ranking results, a frequency polygon was plotted to show the number of individual responses for each scale value. At first glance, the top polygon in Figure 14 suggests a near normal distribution of scores. However, closer examination of the frequency indicated the normal key responses outnumbered the low and high key responses by ten times. Because of this result, it was thought the original sample population of prints might have been biased with too many normal key images. To investigate

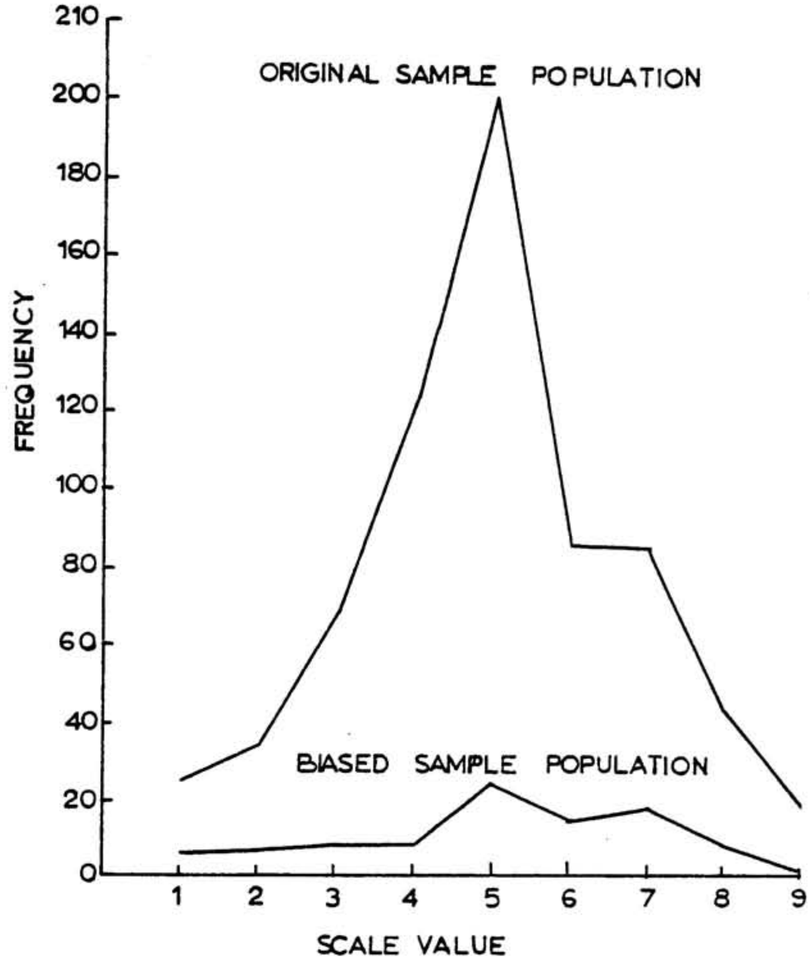

Figure 14.
Frequency distributions of scores for original and biased sample populations. Scale values one, five, and nine respectively represent low, normal, and high key scores.

this, exploratory ranking sessions were given to five people with the same instructions and viewing conditions as the first subjective test. This time, only three normal key prints were included in the sample population. Limiting this population to three normal key images produced a smoother frequency distribution as shown in the bottom polygon of Figure 14.

Simultaneous vs. Sequential Viewing

To see if there was any difference between sequential ranking (one at a time) and simultaneous ranking (all at one time); five more people were asked to rank the new biased sample population. The prints were randomly displayed on a table under a measured light intensity range of 70 to 85 foot-candles. The judges were asked to first view the images, and then place each print in a numbered space representing their subjective scale value. The broken-line in Figure 15 indicates a different distribution of scores than the distribution plotted from the scores of the sequential tests. They are indicated by the solid-line distribution in Figure 15.

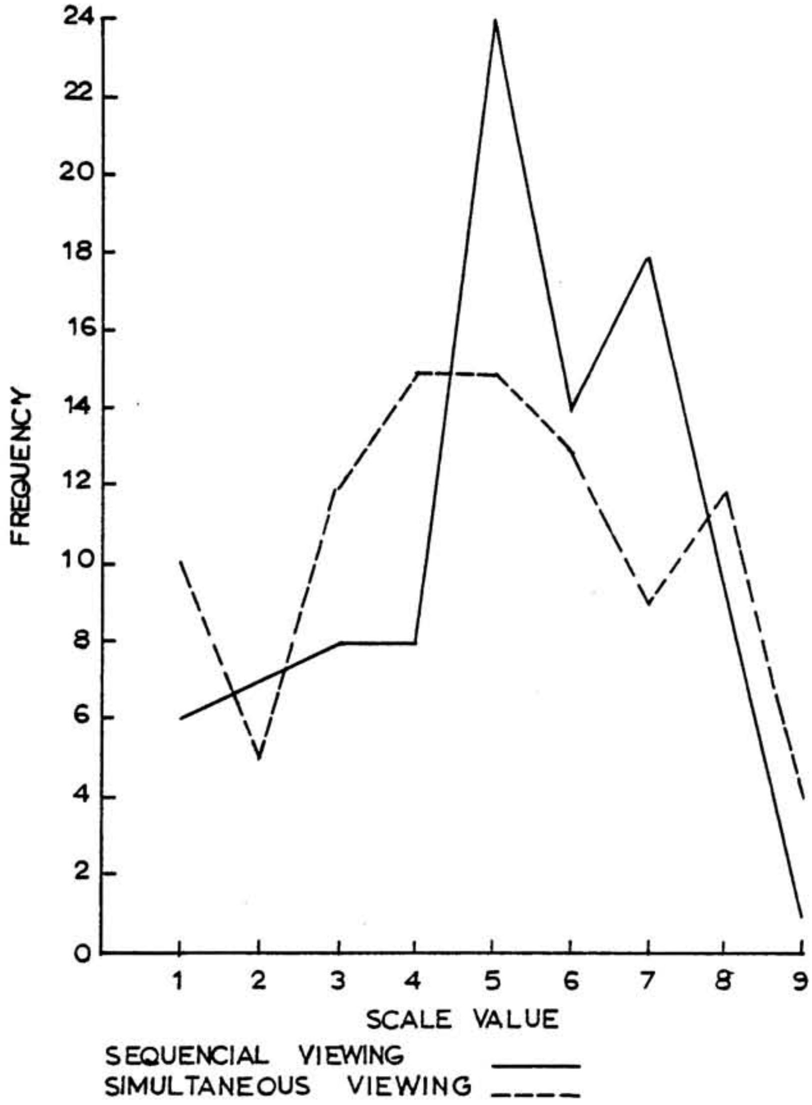

Figure 15.
Frequency Distributions of Biased Sample Population Ranked Sequentially and Simultaneously by five people.

Recommendations

Since the exploratory simultaneous viewing sessions did produce a different frequency distribution, further investigation between sequential and simultaneous ranking is suggested. If all the images used in this study were simultaneously ranked in another investigation of this type; their subjective mean scores could be correlated with the sequential ranking mean scores (derived in this study) to find their relationship.

Regarding objective measurements, it is only reasonable to consider a larger sample size when a less tedious method becomes available, such as the scanning device. With the aid of the scanning instrument, and appropriate statistical analysis, it is believed that a relationship between the subjective ranking of images and an objective measure of the TDC can be found when a larger sample of objective data is used.

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BIBLIOGRAPHY

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, Color Scanner Series 70/8800 Operating Manual, RCA Graphics Systems, November, 1968.

APPENDIX A

APPENDIX A

THE JONES DIAGRAM

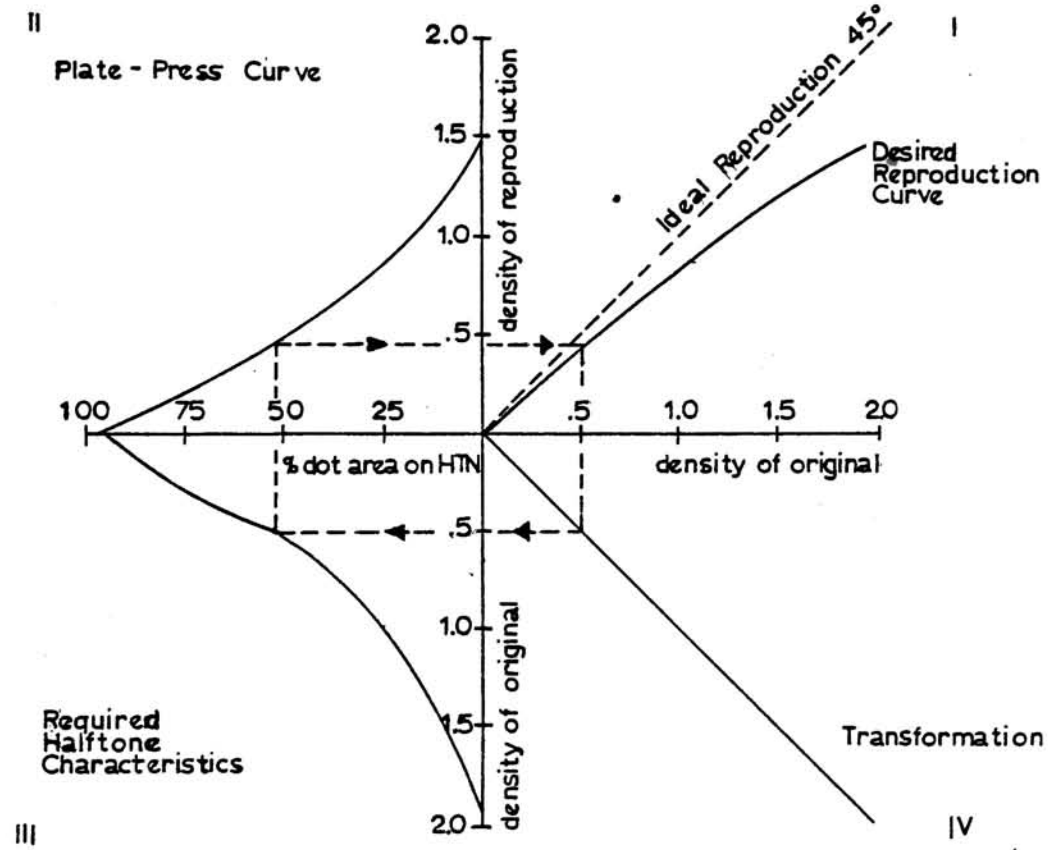

Figure 16.
Jones Diagram for Black and White.

Quadrant I graphically describes the desired tone reproduction characteristics between the original and the photomechanical reproduction. This relationship is a curve plotted in terms of corresponding density measurements that are obtained from the original and the reproduction. It is expressed within the solid ink density limitations of a particular printing process.

Quadrant II, often called the plate-press curve, is an illustration of the printing characteristics. They are acquired from the end product results of a particular ink, plate, press and paper combination. The curve expresses the relationship between percent dot areas of the halftone negative plotted against the resulting tint densities of the reproduction press sheet.

Quadrant III describes the required halftone characteristics. These will become the halftone screening requirements needed to achieve the desired tone reproduction characteristics in quadrant I. They are generated from the relationship between the densities of the original and the percent dot areas of the given halftone screening. The curve is referred to as the required halftone characteristics or sometimes, the required camera curve.

Quadrant IV contains a 45° straight line which is used for transformation purposes. The arrows represent the direction of transformation of data from one quadrant to the next. In most cases, the maximum solid ink density of the reproduction is limited by the capabilities of the particular printing process.[1-2]

APPENDIX B

APPENDIX B

THE ZONE SYSTEM

The zone system is a photographic technique for analyzing the scene classification of tone reproduction. The zones are divided into nine categories related to tone gradation. High, normal, and low key images are distinguished by nine subjective descriptions and examples as follows:

Zone 1. black
2. slightly less than black
3. just perceptible detail
4. open shadows
5. 18% gray
6. normal caucasian skin
7. heavy texture; i.e., concrete
8. delicate texture; i.e., a cloud
9. white

When the main interest area is predominately of light tones, it is considered high key. Most high key images are said to be within zones 9, 8, 7 1/2. A normal key image contains the entire range of tone gradation, zones 1 through 9. Low key deals primarily with dark tones, zones 1 through 4. It is interesting to note that the low key main interest area must also have a highlight. On the otherhand, a high key main interest area does not require a black. The photographer uses the zone system so that he can expose in such a manner that the area he defines as shadow detail will have the detail that he wants. Then he can modify the development so that the area he defines as highlights will have highlights.[3]

APPENDIX C

APPENDIX C

INSTRUCTIONS FOR SUBJECTIVE CLASSIFICATION AND RANKING OF SCENE CATEGORY

I. Introduction:

You are asked to evaluate 31 black and white pictures in terms of representing varying degrees of scene classification. In the past, scene classification has been divided into three main categories called low key, normal key, and high key.

II. Please refer to the given examples:

1. A low key image is predominatly of dark tones. However, it must also have a highlight (white).

2. A normal key image contains the entire range of tones, such as white, grays, and black. There is generally no predominance of one tone over the other.

3. A high key image is predominatly of light tones. Information is contained in the subtle differences in light tones. It does not require a black.

III. Procedure:

1. Classify each image by deciding whether it is obviously low key, normal key, high key or somewhere in between.

2. An arbitrary, nine value, scale is shown with the given obvious examples of low, normal, and high key images.

3. The low scale values represent a low key image. The middle scale values indicate a normal key image. A high key image is represented by the high scale values.

low key				normal key				high key
1	2	3	4	5	6	7	8	9

APPENDIX D

N.F. BUTCHER

Figure 17.
Obvious Low Key Sample

PASCHA BAKER

Figure 18.
Obvious Normal Key Sample

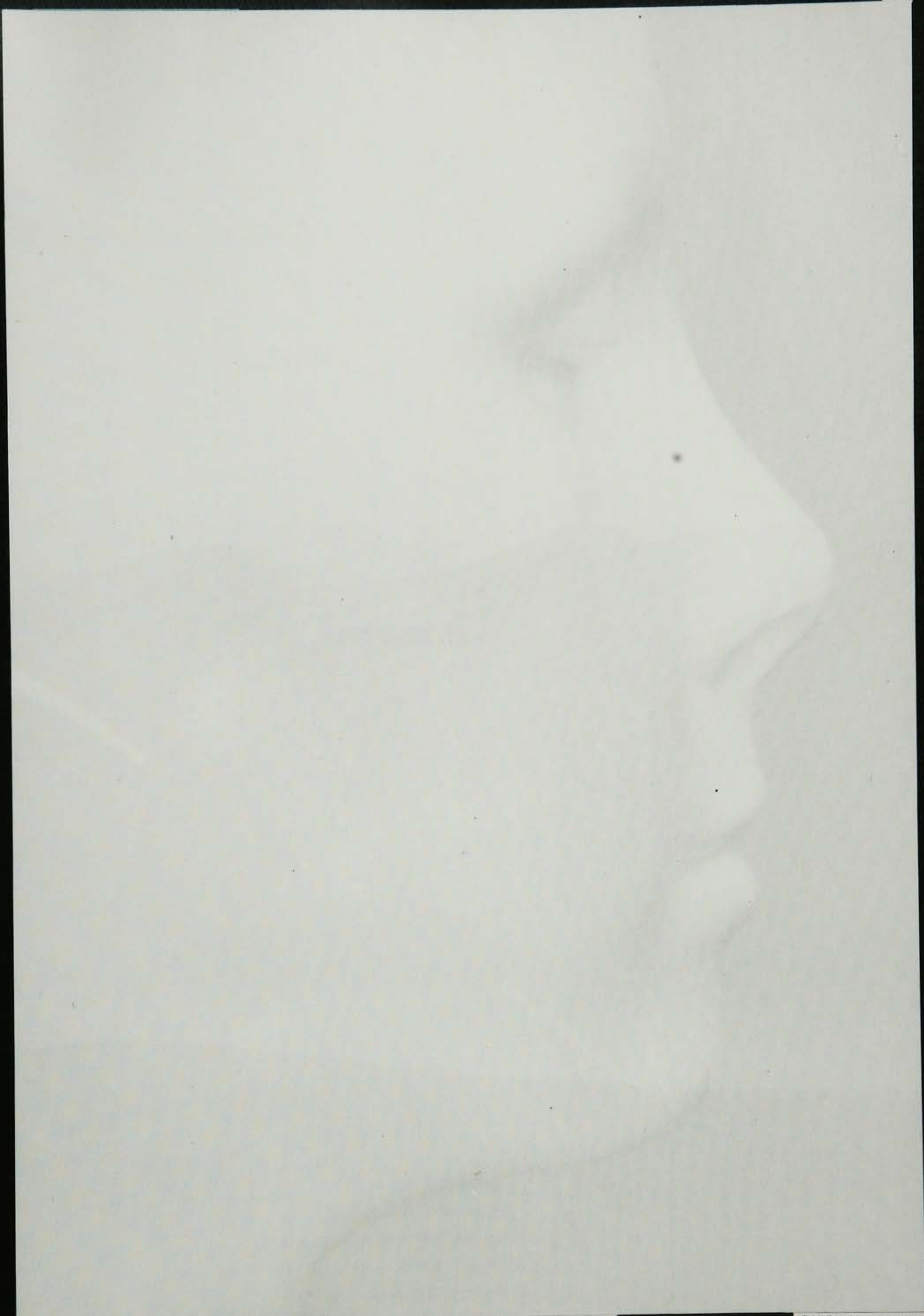

Figure 19.
Obvious High Key Sample

PATRICK BROWN

APPENDIX E

APPENDIX E

THE COMPUTER LISTING OF SUBJECTIVE RAW DATA AND STATISTICS

Table 1.
Computer listing of subjective raw data.

OBSERVER NUMBER

PRINT NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	PRINT NUMBER
1	7	5	5	6	5	5	6	5	6	7	5	6	6	6	7	6	5	5	7	5	5	6	1
2	6	6	4	5	5	5	5	4	5	5	5	5	5	5	5	4	5	4	5	5	5	5	2
3	6	5	4	5	5	5	6	5	5	6	5	6	5	6	6	6	6	7	5	6	6	5	3
4	2	4	4	3	3	3	5	4	3	2	1	2	4	4	2	4	3	2	3	4	3	3	4
5	3	4	4	4	3	2	4	3	4	3	1	3	4	4	4	4	4	3	3	4	4	4	5
6	8	7	6	7	9	7	7	7	7	6	9	6	7	7	7	7	6	7	7	6	7	7	6
7	5	4	5	3	4	3	4	3	5	4	1	3	5	5	2	5	5	3	4	5	4	4	7
8	7	8	7	8	7	6	7	6	6	7	9	7	7	7	6	8	6	9	7	6	7	7	8
9	4	5	4	4	3	5	5	5	4	4	5	5	4	4	4	4	4	4	3	2	4	4	9
10	5	6	5	4	4	4	5	5	4	5	5	4	5	5	3	4	5	5	4	5	5	5	10
11	7	7	7	6	6	7	6	7	7	7	7	7	6	7	8	7	6	7	6	7	6	6	11
12	7	6	7	6	6	6	7	6	6	7	9	7	6	7	7	8	6	7	7	6	6	6	12
13	5	3	5	4	5	3	5	4	4	4	3	5	3	3	3	5	5	5	3	4	4	4	13
14	5	2	2	5	5	3	5	5	3	5	7	5	5	4	2	4	5	5	4	4	6	4	14
15	4	4	6	5	4	4	5	5	5	5	5	5	5	5	4	5	5	5	4	5	5	5	15
16	4	5	5	5	4	3	5	5	4	5	7	4	5	4	4	5	5	4	4	5	4	4	16
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18	7	6	6	7	7	7	7	5	6	7	9	7	7	6	8	8	7	8	7	8	6	7	18
19	8	7	7	7	8	8	7	6	7	7	8	8	7	7	7	8	7	7	8	6	7	6	19
20	9	8	8	8	9	7	8	6	8	9	9	9	8	8	8	9	8	9	8	8	8	8	20
21	3	3	3	3	4	4	3	3	3	4	1	4	3	4	3	2	4	2	4	3	4	4	21
22	2	4	4	5	3	4	4	5	3	4	3	5	4	3	2	5	5	3	4	5	5	4	22
23	4	4	3	3	2	4	3	2	2	3	1	3	3	2	4	4	3	2	3	4	4	4	23
24	5	5	5	5	5	5	5	5	5	5	3	5	5	5	5	5	4	5	4	4	5	5	24
25	5	4	4	5	4	4	4	5	4	4	5	4	5	4	5	5	5	5	4	4	5	5	25
26	5	5	6	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	5	6	5	5	26
27	6	5	7	6	6	5	6	5	6	5	9	6	5	6	6	7	5	6	7	5	6	4	27
28	6	6	6	5	4	5	5	5	5	6	3	6	5	5	5	5	5	5	4	5	5	5	28
29	9	8	8	8	8	6	8	6	7	8	9	9	7	8	8	9	8	8	8	7	8	8	29
30	1	2	3	2	3	3	2	3	1	1	5	2	2	1	1	3	3	1	1	2	3	3	30
31	1	2	2	1	3	3	1	1	1	2	1	2	2	1	1	2	1	1	1	1	2	2	31
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	

OBSERVER NUMBER

Table 2.
Computer listing of statistics for subjective ranking of images.

STATS PRINT	POP.	MAXIMUM	MINIMUM	RANGE	MEAN	VARIENCE	ST.DEV.	MEAN DEV	MEDIAN
1	22	7	5	2	5.73	0.589	0.767	0.661	5.5
2	22	6	4	2	4.91	0.277	0.526	0.331	5
3	22	7	4	3	5.5	0.452	0.673	0.591	5.5
4	22	5	1	4	3.09	0.944	0.971	0.752	1.5
5	22	4	1	3	3.45	0.641	0.8	0.645	2
6	22	9	6	3	7	0.667	0.816	0.455	7.5
7	22	5	1	4	3.91	1.23	1.11	0.851	2
8	22	9	6	3	7.05	0.807	0.899	0.616	8
9	22	5	2	3	4.09	0.563	0.75	0.496	5
10	22	6	3	3	4.64	0.433	0.658	0.554	4.5
11	22	8	6	2	6.68	0.323	0.568	0.496	7
12	22	9	6	3	6.64	0.623	0.79	0.636	8
13	22	5	3	2	4.05	0.712	0.844	0.694	4
14	22	7	2	5	4.32	1.66	1.29	1.02	6
15	22	6	4	2	4.77	0.279	0.528	0.421	5
16	22	7	3	4	4.55	0.641	0.8	0.636	5.5
17	22	7	5	2	5.32	0.323	0.568	0.463	5.5
18	22	9	5	4	6.95	0.807	0.899	0.612	8
19	22	8	6	2	7.18	0.442	0.664	0.521	8
20	22	9	6	3	8.18	0.537	0.733	0.521	9
21	22	4	1	3	3.23	0.66	0.813	0.632	2.5
22	22	5	2	3	3.91	0.944	0.971	0.76	4
23	22	4	1	3	3.05	0.807	0.899	0.694	2
24	22	5	3	2	4.77	0.279	0.528	0.372	4
25	22	5	4	1	4.5	0.262	0.512	0.5	4.5
26	22	6	4	2	5.05	0.141	0.375	0.174	5
27	22	9	4	5	5.86	1.08	1.04	0.719	7.5
28	22	6	3	3	5.05	0.522	0.722	0.434	4.5
29	22	9	6	3	7.86	0.695	0.834	0.574	9
30	22	5	1	4	2.18	1.11	1.05	0.851	3.5
31	22	3	1	2	1.55	0.45	0.671	0.595	1.5

APPENDIX F

APPENDIX F

THE PDP-8 PROGRAM LISTING FOR ARRANGING DENSITY MEASUREMENTS INTO EQUAL MUNSELL INCREMENTS

```
101 '
126 RECORD A(50)
151 PRINT\ PRINT "'ENTER.BAS'-ENTER THE DENSITOMETER READINGS"
176 PRINT\ PRINT\ PRINT "WHAT IS THE NAME OF THE DATA FILE";
201 INPUT X$
226 OPEN 8,X$
251 PRINT\ PRINT "WHAT IS THE STARTING RECORD NUMBER (NORMALLY 0)";\ INPUT S
276 LET J=S
301 PRINT\ PRINT "DO YOU WANT TO (1) ENTER DATA, OR (2) JUST LIST THE"
326 PRINT "DATA ON THE LINE PRINTER";
351 INPUT D1
376 IF D1=2 THEN 1401
401 PRINT\ PRINT "HOW MANY PICTURES TO READ";\ INPUT P
426 PRINT\ PRINT "HOW MANY GROUPS OF 50 READINGS PER PICTURE";\ INPUT G
451 PRINT\ PRINT
476 PRINT "TYPE '-999' TO TERMINATE THE CURRENT PICTURE"
501 PRINT "AND GO ON TO A NEW ONE."\ PRINT
526 PRINT\ PRINT "PROCEED."
551 PRINT\ PRINT
576 FOR X=1 TO P
601 PRINT "PICTURE NUMBER =";X
626 FOR T=1 TO G
651 FOR Z=1 TO 50
676 LET A(Z)=0
701 NEXT Z
726 PRINT "GROUP #";T
751 PRINT "RECORD #";
776 LET R1=J
801 PRINT R1
826 FOR Y=1 TO 50
830 PRINT "READ #";Y;
850 INPUT A(Y)
851 IF A(Y)=-999 THEN 1101
852 IF A(Y)>2.11 THEN 875
853 IF A(Y)>1.75 THEN 876
854 IF A(Y)>1.50 THEN 877
855 IF A(Y)>1.30 THEN 878
856 IF A(Y)>1.14 THEN 879
857 IF A(Y)>1.00 THEN 880
858 IF A(Y)>.88 THEN 881
859 IF A(Y)>.77 THEN 882
860 IF A(Y)>.67 THEN 883
861 IF A(Y)>.58 THEN 884
862 IF A(Y)>.50 THEN 885
863 IF A(Y)>.42 THEN 886
864 IF A(Y)>.34 THEN 887
865 IF A(Y)>.27 THEN 888
866 IF A(Y)>.21 THEN 889
867 IF A(Y)>.14 THEN 890
868 IF A(Y)>.08 THEN 891
```

```
 869 IF A(Y)>.025 THEN 892
 870 IF A(Y)>0.00 THEN 893
 871 PRINT\PRINT "ERROR IN READING !!!!"
 872 PRINT\PRINT "PLEASE REENTER THE VALUE";\GOTO 850
 875 A(Y)=1.0\GOTO 900
 876 A(Y)=1.5\GOTO 900
 877 A(Y)=2.0\GOTO 900
 878 A(Y)=2.5\GOTO 900
 879 A(Y)=3.0\GOTO 900
 880 A(Y)=3.5\GOTO 900
 881 A(Y)=4.0\GOTO 900
 882 A(Y)=4.5\GOTO 900
 883 A(Y)=5.0\GOTO 900
 884 A(Y)=5.5\GOTO 900
 885 A(Y)=6.0\GOTO 900
 886 A(Y)=6.5\GOTO 900
 887 A(Y)=7.0\GOTO 900
 888 A(Y)=7.5\GOTO 900
 889 A(Y)=8.0\GOTO 900
 890 A(Y)=8.5\GOTO 900
 891 A(Y)=9.0\GOTO 900
 892 A(Y)=9.5\GOTO 900
 893 A(Y)=10.0\GOTO 900
 900 NEXT Y
 926 PUT 8,126,J
 951 PRINT\ PRINT "******END OF GROUP******"
 976 PRINT
1001 NEXT T
1026 PRINT\ PRINT "********** END OF PICTURE **********"
1051 PRINT\ PRINT
1076 GOTO 1151
1101 PUT 8,126,J
1126 PRINT\ PRINT "**********EARLY END OF PICTURE**********"
1151 NEXT X
1176 PRINT\ PRINT
1201 PRINT CHR$(7);CHR$(7);CHR$(7);CHR$(7);CHR$(7)
1226 PRINT "****************** END OF THE RUN **********************"
1251 LET A(1)=888 'THIS IS TO DETECT THE END OF THE FILE
1276 PUT 8,126,J
1301 PRINT\ PRINT "DO YOU WISH TO HAVE A LINE PRINTER COPY OF YOUR DATA";
1326 INPUT L$
1351 IF L$="YES" THEN 1401
1376 GOTO 1826
1401 LPRINT\ LPRINT "DENSITOMETER DATA POINTS STORED IN THE FILE = '";
1426 LPRINT X$;"'."
1451 LPRINT
1476 LPRINT
1501 LET J=0
1526 FOR H=1 TO 10000
1530 LET R1=J
1551 GET 8,126,J
1576 IF A(1)=888 THEN 1826
1601 LPRINT "RECORD #";
1651 LPRINT R1
1676 LPRINT
1701 FOR X=1 TO 50
1726 LPRINT A(X),
1751 NEXT X
1776 LPRINT\ LPRINT
1801 NEXT H
1826 CLOSE 8
1851 END
```

PDP-8 PROGRAM LISTING TO PUNCH

MUNSELL INCREMENTS ONTO PAPER TAPE

```
  50 RECORD A(50)
 100 PRINT\PRINT "'PUNCH.BAS' - PUNCH OUT A DATA FILE ONTO PAPER TAPE"
 110 PRINT
 120 PRINT "WHAT IS THE NAME OF THE DATA FILE TO PUNCH";\INPUT X$
 130 OPEN 9,X$
PE34 PRINT\PRINT "WHEN FINISHED, YOU HAVE 1 MINUTES TO PUNCH A TRAILER ON THE TA
 135 PRINT\PRINT "MAKE SURE THAT THE PUNCH IS READY"
 136 PRINT\PRINT "TYPE A RETURN WHEN YOU ARE READY TO GO";\INPUT G$
 140 LET J=0
 150 GET 9,50,J
 170 FOR X=1 TO 50
 175 IF A(X)=-999 THEN 500
 180 PRINT A(X)
 190 NEXT X
 200 GOTO 150
 500 SLEEP 60
 600 PRINT\PRINT "DO YOU WISH TO PUNCH ANOTHER FILE";\INPUT A$
 700 IF A$="YES" THEN 110
1000 CLOSE 9
1500 END
```

APPENDIX G

APPENDIX G

APL FUNCTIONS FOR CALCULATION OF TDCs

These APL functions sorted all Munsell data on tape into twenty equal Munsell value intervals. The functions were also used to call up appropriate programs in the Sigma IX computer to calculate the absolute, cumulative, and relative cumulative frequency of the image lightnesses.

```
      ∇ PROCESS FID;T;T1;T2;T3;T4
[1]     T←BLINDINPUT FID
[2]     T1←⌽0,0.5×⍳20⍝ MUNSELL VALUES
[3]     T2←FREQ T
[4]     T3←CUMFREQ T
[5]     T4←RELCUMFREQ T
[6]     ' '
[7]     ' '
[8]     'ANALYSIS FOR ',FID
[9]     ' '
[10]    '    M    AF    CF    RCF'
[11]    'F4.1,I5,I5,F6.2'ΔFMT(T1;T2;T3;T4)
[12]    ' '
[13]    ' '
[14]    ' '
[15]    ' '
[16]    ' '
[17]    ' '
      ∇
```

```
      ∇ R←RELCUMFREQ A
[1]     R←(CUMFREQ A)÷⍴A
      ∇
```

APPENDIX H

APPENDIX H

APL COMPUTED DATA ANALYSIS FOR PLOTTING OF EIGHT TONE DISTRIBUTION CURVES

Table 3.
Analysis for first three samples of low (31), normal (26), and high key (11) images. These prints had the lowest standard deviations. The column headings are as follows: M = Munsell, AF = Absolute Frequency, CF = Cumulative Frequency, and RCF = Relative Cumulative Frequency.

ANALYSIS FOR PRINT31

M	AF	CF	RCF
10.0	0	0	0.00
9.5	0	0	0.00
9.0	5	5	0.02
8.5	0	5	0.02
8.0	1	6	0.02
7.5	7	13	0.05
7.0	1	14	0.05
6.5	2	16	0.06
6.0	0	16	0.06
5.5	6	22	0.08
5.0	4	26	0.09
4.5	0	26	0.09
4.0	0	26	0.09
3.5	11	37	0.13
3.0	18	55	0.19
2.5	2	57	0.20
2.0	4	61	0.21
1.5	224	285	1.00
1.0	0	285	1.00
0.5	0	285	1.00
0.0	0	285	1.00

ANALYSIS FOR PRINT26

M	AF	CF	RCF
10.0	0	0	0.00
9.5	0	0	0.00
9.0	30	30	0.11
8.5	15	45	0.16
8.0	9	54	0.19
7.5	9	63	0.22
7.0	20	83	0.29
6.5	18	101	0.35
6.0	15	116	0.41
5.5	19	135	0.47
5.0	27	162	0.57
4.5	32	194	0.68
4.0	23	217	0.76
3.5	18	235	0.82
3.0	10	245	0.86
2.5	23	268	0.94
2.0	11	279	0.98
1.5	6	285	1.00
1.0	0	285	1.00
0.5	0	285	1.00
0.0	0	285	1.00

ANALYSIS FOR PRINT11

M	AF	CF	RCF
10.0	0	0	0.00
9.5	0	0	0.00
9.0	26	26	0.09
8.5	111	137	0.48
8.0	50	187	0.66
7.5	19	206	0.72
7.0	9	215	0.75
6.5	7	222	0.78
6.0	15	237	0.83
5.5	15	252	0.88
5.0	11	263	0.92
4.5	15	278	0.98
4.0	1	279	0.98
3.5	1	280	0.98
3.0	2	282	0.99
2.5	2	284	1.00
2.0	1	285	1.00
1.5	0	285	1.00
1.0	0	285	1.00
0.5	0	285	1.00
0.0	0	285	1.00

Table 4

Analysis for second three samples of low (30), normal (14), and high key (12) images. These prints had the highest standard deviation.

ANALYSIS FOR PRINT30

M	AF	CF	RCF
10.0	0	0	0.00
9.5	0	0	0.00
9.0	4	4	0.01
8.5	2	6	0.02
8.0	3	9	0.03
7.5	2	11	0.04
7.0	1	12	0.04
6.5	2	14	0.05
6.0	1	15	0.05
5.5	3	18	0.06
5.0	5	23	0.08
4.5	1	24	0.08
4.0	8	32	0.11
3.5	3	35	0.12
3.0	6	41	0.14
2.5	53	94	0.33
2.0	191	285	1.00
1.5	0	285	1.00
1.0	0	285	1.00
0.5	0	285	1.00
0.0	0	285	1.00

ANALYSIS FOR PRINT14

M	AF	CF	RCF
10.0	0	0	0.00
9.5	0	0	0.00
9.0	72	72	0.25
8.5	21	93	0.33
8.0	6	99	0.35
7.5	0	99	0.35
7.0	4	103	0.36
6.5	5	108	0.38
6.0	2	110	0.39
5.5	2	112	0.39
5.0	4	116	0.41
4.5	5	121	0.42
4.0	3	124	0.44
3.5	1	125	0.44
3.0	4	129	0.45
2.5	7	136	0.48
2.0	10	146	0.51
1.5	139	285	1.00
1.0	0	285	1.00
0.5	0	285	1.00
0.0	0	285	1.00

ANALYSIS FOR PRINT12

M	AF	CF	RCF
10.0	0	0	0.00
9.5	0	0	0.00
9.0	81	81	0.28
8.5	11	92	0.32
8.0	24	116	0.41
7.5	31	147	0.52
7.0	51	198	0.69
6.5	28	226	0.79
6.0	22	248	0.87
5.5	11	259	0.91
5.0	11	270	0.95
4.5	4	274	0.96
4.0	2	276	0.97
3.5	6	282	0.99
3.0	1	283	0.99
2.5	2	285	1.00
2.0	0	285	1.00
1.5	0	285	1.00
1.0	0	285	1.00
0.5	0	285	1.00
0.0	0	285	1.00

Table 5.
Analysis for last two samples having subjective mean scores in between high and normal key (27) and normal and low key (21).

ANALYSIS FOR PRINT27

M	AF	CF	RCF
10.0	0	0	0.00
9.5	49	49	0.17
9.0	50	99	0.35
8.5	26	125	0.44
8.0	18	143	0.50
7.5	11	154	0.54
7.0	8	162	0.57
6.5	9	171	0.60
6.0	8	179	0.63
5.5	4	183	0.64
5.0	3	186	0.65
4.5	1	187	0.66
4.0	4	191	0.67
3.5	4	195	0.68
3.0	3	198	0.69
2.5	18	216	0.76
2.0	69	285	1.00
1.5	0	285	1.00
1.0	0	285	1.00
0.5	0	285	1.00
0.0	0	285	1.00

ANALYSIS FOR PRINT21

M	AF	CF	RCF
10.0	0	0	0.00
9.5	0	0	0.00
9.0	0	0	0.00
8.5	0	0	0.00
8.0	0	0	0.00
7.5	0	0	0.00
7.0	0	0	0.00
6.5	3	3	0.01
6.0	1	4	0.01
5.5	9	13	0.05
5.0	12	25	0.09
4.5	11	36	0.13
4.0	21	57	0.20
3.5	19	76	0.27
3.0	37	113	0.40
2.5	49	162	0.57
2.0	78	240	0.84
1.5	45	285	1.00
1.0	0	285	1.00
0.5	0	285	1.00
0.0	0	285	1.00

APPENDIX I

APPENDIX I

SIGMA IX COMPUTER OUTPUT FOR CORRELATION COEFFICIENT OF EXPERIENCED vs. NAIVE OBSERVERS

Table 6.
Computer listings of correlation coefficient for experienced vs. naive observers.

PRINT	EXP X	NAIVE Y
1:	5.7	5.75
2:	5	4.92
3:	5.4	5.67
4:	3	3.08
5:	3.4	3.42
6:	7.2	7.08
7:	3.9	3.83
8:	7.4	6.75
9:	4.0	4.08
10:	4.7	4.50
11:	6.4	6.83
12:	6.7	6.50
13:	3.9	4.17
14:	4.8	4.17
15:	4.7	4.67
16:	4.9	4.17
17:	5.2	5.33
18:	7.1	6.92
19:	7.4	7.08
20:	8.4	8.08
21:	3.2	3.33
22:	4.2	3.58
23:	3.0	3.00
24:	4.6	4.92
25:	4.6	4.42
26:	5.0	5.00
27:	6.1	5.58
28:	4.8	5.08
29:	8.1	7.67
30:	2.5	1.92
31:	1.7	1.50
MEAN	5.06451	4.93548
ST DEV	1.67482	1.63976

R = .982074   B(Y,X) = .961516

FOOTNOTES FOR APPENDICES

1. Rhodes, Warren L., "Tone and Color Control in Reproduction Processes," TAGA Proceedings, 1954, p. 48-61.

2. Yule, John A.C., Plot Tone Reproduction Curves, Graphic Arts Research Center, Rochester Institute of Technology, Rochester, N.Y., Report No. 127, 1968, p. 1-11.

3. Bollman, Terry, Private Communication, 1977.